RECALL OF DIGITS FROM THE LEFT AND RIGHT VISUAL FIELDS UNDER FREE AND FIXED ORDER OF REPORT

By

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INTRODUCTION

Considerable controversy has been sparked over the past two decades about the relationship between lateralized speech dominance in the cerebral hemispheres and behavioral measures of lateral asymmetries. Specifically, it has been hypothesized that hand dominance (Milner, 1964), ear asymmetry on the Dichotic Listening Test (Satz, 1968), and visual field asymmetry on tachistoscopic recognition tasks (Kimura, 1966) are all related to the lateralization of verbal and nonverbal functions in the human brain. The experiments to be reported in this paper deal with the development of a new technique for measuring visual field asymmetries and their relationship to the cortical lateralization of language functions. These experiments are based on information gained through studies relating handedness, ear asymmetry, and visual field asymmetry to speech dominance. These studies will now be reviewed, with the primary emphasis on the visual field studies.

Relationship Between Handedness and Hemispheric Speech Dominance

The relationship between speech laterality and handedness is well documented, although many aspects of this relationship are still unclear. It has long been suggested (e.g. Steir, 1911) that right-handed persons tend to be left-brained for speech, while left-handed persons tend to have speech functions localized in the right hemisphere. The first evidence for this relationship came from studies of aphasic patients, where different consequences of right hemisphere lesions

were noted between sinistrals and dextrals. Following a lesion to the right hemisphere, only about one per cent of right-handed patients but 30 per cent of left-handed cases displayed aphasic symptoms (Zangwill, 1960).

More definitive evidence concerning speech-brain lateralization and handedness comes from studies using the intracarotid sodium amytal test of speech (Wada and Rasmussen, 1960). This procedure, which is used clinically to determine speech lateralization in neurosurgery patients, enables the selective suppression of one hemisphere through unilateral injection of sodium amytal into the carotid artery. Because of medical risks this technique cannot be used with normal Ss.

Branch, Milner and Rasmussen (1964) used the sodium amytal procedure to evaluate cerebral speech dominance in a series of 123 patients. Forty-one of their patients were right-handed, 47 were left-handed and 17 were classified as ambidextrous. These patients were being considered for brain surgery for the relief of focal cerebral seizures. This study demonstrated clear differences in lateralization of speech functions between left- and right-handed patients, with the latter showing a significantly higher percentage of left-brained speech representation. Left hemispheric speech representation was demonstrated for 90 per cent of the right-handed Ss and only 64 per cent of the left-handed or ambidextrous patients. An additional 16 per cent of the left-handed patients demonstrated bilateral cerebral representation of speech functions. Direct tests of the lateralization of speech functions have also been carried out using electrical stimulation of the brain during neurosurgery (Penfield and Roberts, 1959).

Despite the introduction of this new medical technique, which is most definitive in determining the cortical lateralization of speech functions, it cannot answer problems which arise with regard to the normal development of lateralized speech since it can only be employed with candidates for brain surgery, all of whom already possess some type of central nervous system disorder. Differences between this group and cortically intact Ss may make generalization to population norms unreliable. Also, the use of only brain-injured Ss prevents measurement of ontological and behavioral correlates of the normal development of cortical lateralization. For example, it is not known whether differences in intelligence exist between persons with left, right, or bilateral speech representation. In addition, it has been suggested that developmental dyslexia may be associated with a failure to develop cortical lateralization for speech functions (Benton, 1960, Delacato, 1959). Finally, the age at which speech lateralization occurs in children is unclear, with estimates ranging from age two (Penfield and Roberts, 1959), four to six (Kimura, 1963) and up to puberty (Lenneberg, 1967). The failure of neurosurgical techniques (e.g. Wada test, ablations) and the observation of deficits produced by brain lesions to answer these questions has resulted in the development of special techniques which attempt to measure the cerebral lateralisation of speech functions in cortically intact Ss.

Development of Behavioral Measures of Hemispheric Language Dominance

Over the past 15 years, extensive studies in vision and audition have disclosed lateralized differences in the processing of verbal and

nonverbal data which are apparently related to the phenomenon of functional lateralization of speech within the cerebral hemispheres. These measures have seemingly provided an easily accessible, although less precise, way of estimating whether a person is left or right hemispheric dominant for language functions. However, it has been suggested that these techniques are not, in fact, measures of speech lateralization but of other, learned, effects. The auditory asymmetry has been attributed to order of report phenomena (Oxbury, Oxbury, and Gardner, 1967) and visual field asymmetries to reading habit (Heron, 1957). However, this paper will show in its review that convincing evidence does exist that the auditory asymmetry and the visual field asymmetry are related to the functional asymmetry of the cerebral hemispheres.

Auditory Studies

Studies in audition have utilized the Dichotic Listening Technique, developed by Broadbent in 1954. Groups of digit pairs are presented simultaneously to each ear, with recall immediately following completion of a group (e.g. 3-pairs, 4-pairs, etc.). The stimuli are presented so that one-half of a digit pair is presented to one ear at the same time as the second half is presented to the other ear. Broadbent (1954) devised this technique in order to study short term memory processes and developed a theoretical model of short term memory, based upon the observation that Ss tended to report all the digits presented to one ear before recalling digits presented to the other ear. Broadbent hypothesized that the digits from the ear reported

second were shunted into a temporary short term store while the digits to the ear reported first were being processed.

Kimura (1961a, 1961b) utilized this technique to determine the integrity of memory processes subsequent to lesions in the temporal lobes. Lobectomy of either the left or the right temporal lobe was found to produce a significant deficit in recall for information presented to the contralateral ear. Kimura also found that, regardless of the site of the lesion, superior recall for digits was obtained in the ear contralateral to the hemisphere dominant for speech (as determined by the Wada sodium amytal test). This ear asymmetry was demonstrated only under conditions of binaural, simultaneous stimulation.

These findings led Kimura to suggest that the Dichotic Listening Test was correlated with speech-brain laterality. The ear contralateral to the dominant speech hemisphere was superior to the ear, suggesting that the contralateral pathways for processing verbal material are more efficient under conditions of simultaneous stimulation. Earlier work with the cat (Rosenzweig, 1951) and the dog (Tunturi, 1946) demonstrate that, in fact, contralateral auditory fibers do predominate under both monaural and binaural auditory stimulation. This finding has recently been confirmed by Sparrow, Knapp, King and Roberts (1967) presenting clicks monaurally and binaurally to cats. Satz (1968) has pointed out that this explanation of the right ear superiority on the Dichotic Listening Test invokes an asymmetry at two levels of brain function, "(1) lateralization or 'dominance' at the level of the cortex, in this case, speech and language and (2)

more numerous or more efficient pathways subserving contralateral connections up to the cortex" (p. 277).

Kimura (1964) further demonstrated that these contralateral effects also occur for nonverbal auditory material, for which superior recall was found in the ear contralateral to the "nondominant" hemisphere. Thus, while one hemisphere, usually the left, predominates in the processing of language functions, the other hemisphere predominates in the processing of nonverbal data such as melodies. Kimura found that under conditions of simultaneous stimulation, right-handed Ss typically show better recall for verbal material from the right ear and better recognition of melodies from the left ear.

Several investigators have demonstrated differences in ear asymmetry between left- and right-handers using the Dichotic Listening Test (Bryden, 1963; Satz, et al., 1965). A major handicap of these studies, however, has been their classification of handedness, generally by self-report. Satz, Achenbach, and Fennell (1967) using a multivariate analysis of manual test scores found that hand skills seem to be a more meaningful classification of Ss than the traditional hand preference dichotomy. They administered several manual performance tests and hand preference measures, as well as the Dichotic Listening Test (6 pairs, at 2 pairs/second) to a large group of right- and left-handed Ss. Previous findings of differences in ear asymmetry between right- and left-handers were replicated, with the right-handed Ss showing a larger right ear superiority. Subjects were then assigned to predicted left or right hemisphere speech dominant groups on the basis of their scores on the Dichotic Listening Test. It was found

that the association between handedness and predicted speech-brain dominance was significantly increased if the multivariate hand laterality scores were used as the basis for classification, rather than the traditional subjective report of hand preference. Satz and associates suggested that failure to utilize more refined measures of manual differentiation may obscure the relationships between handedness and speech brain representation.

Criticism of the Dichotic Listening Studies

It has been alleged that the ear asymmetry observed with the Dichotic Listening Studies is unrelated to the functional asymmetry of the cerebral hemispheres but is, instead, merely an artifact of the order of report employed by the Ss (Orkury, et al., 1967). This viewpoint is based on the fact that Ss under conditions of free recall tend to recall digits from the right ear before digits from the left ear. Since the right ear digits are recalled first, a serial order hypothesis would predict a right ear superiority on this basis alone.

Several factors, however, offer convincing evidence that the right ear superiority on the Dichotic Listening Test is related to the functional asymmetry of the hemispheres and the greater efficiency of the contralateral auditory fibers. First, several studies have, in fact, controlled for the order of report and still demonstrated a right ear superiority in Dichotic Listening (Cooper, Satz, Achenbach and Levy, 1967; Bertz, et al., 1967). Second, Kimura (1961) tested patients for whom speech brain laterality was known on the basis of the Wada sodium amytal test and found that speech-brain

asymmetry (Sats, et al., 1967). Fifth, the order of report effect itself suggests that the right ear preference, under free recall conditions, may be a natural result of the more efficient auditory pathways from the right ear to the speech areas of the left cerebral hemisphere.

Visual Studies

In contrast to the auditory system, the visual system offers a more promising opportunity to investigate the functional asymmetry of the cerebral hemispheres because of the complete neuroanatomical separation of the nerve fibers connecting the hemiretinas with the two hemispheres. Information presented to the central area (macula) of each eye is transmitted via crossed and uncrossed pathways to both the left and right hemispheres. Stimuli presented to the visual fields (lateral areas), however, go only to the contralateral hemisphere. Thus, visual stimuli in the left visual field are transmitted directly to the striate cortex of the right hemisphere while stimuli in the right visual field are transmitted directly to the striate cortex of the left hemisphere.

This complete decussation of the visual nerve fibers permits one to test inferences about the asymmetry of the hemispheres through stimulation of the visual fields. It can be predicted that the right visual field should be superior for the processing of verbal information due to its more direct connections to the language areas of the left hemisphere in right-handed persons. Similarly, processing of nonverbal stimuli should be superior for stimuli presented to the left visual visual field because of its more direct connections to the right (nonspeech) hemisphere.

Numerous studies have been done in the tachistoscopic recognition of visual field stimuli which provide some test of these predictions. When verbal stimuli are presented successively either to the left or right of a central fixation point, recognition is generally more accurate in the right visual field (Bryden, 1965) while enumeration of nonverbal material is superior in the left visual field (Kimura, 1966).

The finding of superior tachistoscopic recognition for words in the right visual field under conditions of successive presentation was first noted by Mishkin and Forgays (1952), and has been replicated on numerous occasions (Forgays, 1953; Goodglass and Barton, 1963; Harcum and Finkel, 1963; Orbach, 1952, 1957; Terrance, 1959; Winnick and Dornbush, 1965). Superior recognition on the right visual field has also been found for letters (Bryden, 1964; Bryden and Rainey, 1963; Heron, 1957; Kimura, 1966) and outlines of familiar objects (Wyke and Ettlinger, 1961). Experiments have found no significant differences between the visual fields for tachistoscopic recognition of geometric forms (Bryden, 1960; Bryden and Rainey, 1963; Heron, 1957; Terrance, 1959; Kimura, 1966). A left visual field superiority has been found for enumeration of dots and geometric forms (Kimura, 1966). Thus, differences in visual field asymmetry can be observed, which are related to the type of stimuli presented; that is, verbal stimuli are recognized better in the right visual field, while nonverbal stimuli show no visual field asymmetry or are recognized more accurately in the left visual field. Monocular tachistoscopic presentation of stimuli to the right or left of a central fixation point has also been

demonstrated to result in a right visual field superiority for words (Barton, et al., 1965; Goodglass and Barton, 1963; Overton and Wiener, 1966). These findings apparently fulfill the predictions made on the basis of the decussation of visual nerve fibers and the functional asymmetry of the two hemispheres.

Criticism of the Visual Studies

It has been charged, however, that the right visual field superiority for words in tachistoscopic recognition studies is not due to the effects of speech brain asymmetry but rather to the left-to-right reading habit (Heron, 1957). Heron suggested that when words are presented to the right of fixation, both direction of scanning and the intrinsic characteristics of the stimuli follow the normal left-to-right reading direction. However, when stimuli are presented to the left of fixation, two scanning movements are necessary: a right-to-left movement to the beginning of the word and an additional left-to-right movement to "read" the stimulus. Three findings have traditionally been used to support this hypothesis (Orbach, 1967).

1. Studies had not found a right visual field superiority for Hebrew words, which are read from right to left, when Ss who had learned Hebrew as their native language were tested (Mishkin and Forgays, 1952; Orbach, 1952).

2. When English words were printed from right-to-left, thus reversing the polarity of the words, Ss tended to recognize them more accurately in the left visual field.

3. When words are presented simultaneously to both the left and right visual fields, they are generali recalled more accurately in the left visual field.

All of these findings seem compatible with the directional scanning effects hypothesis and suggest that directional scanning effects are an important source of variation in the tachistoscopic recognition paradigm. There is also evidence, however, that the directional scanning effects are not the sole determinants of the visual field asymmetry and that the visual field asymmetry is also affected by the functional asymmetry of the hemispheres. First, as has already been noted, the visual field asymmetry varies as a result of the type (verbal versus nonverbal) of stimuli presented in a manner consistent with predictions made from the evidence concerning speech brain laterality and visual pathways. Kimura (1966) demonstrated that the same Ss who showed more accurate recognition of letter groups in the right visual field also showed more accurate enumeration of dots and simple geometric figures in the left visual field.

A second finding that supports the importance of speech brain asymmetry in the visual field asymmetry is the difference in visual field asymmetry between left- and right-handers (Bryden, 1965; Orbach, 1967). It can be predicted from speech-brain relationships that left-handers should show less right visual field superiority for verbal materials, since fewer left-handers have speech localized in the left hemisphere (Branch, et al., 1964). This prediction has been confirmed by both Bryden (1965) and Orbach (1967).

A third finding has been Barton et al. (1965) and Orbach's (1967) recent demonstration that right-handed native readers of Hebrew do recognize significantly more English and Hebrew words in the right visual field. Barton et al., under monocular view conditions, presented English and Hebrew words vertically. The vertical presentation would presumably minimize left-to-right or right-to-left directional scanning effects. They found that native readers of Hebrew recognized significantly more English and Hebrew words under this viewing condition, again suggesting speech-brain asymmetry effects. The asymmetry was also found to be greater for the left eye, which has been attributed to the greater sensitivity of the nasal visual field (Kimura, 1966).

Orbach's (1967) study illustrates the interaction of the effects of both speech-brain asymmetry and directional scanning mechanisms. Orbach tested native born Israeli Ss, all of whom had learned Hebrew as their first and English as their second language. He presented both English and Hebrew words binocularly, using successive tachistoscopic presentation. He found that right-handed Ss recognized both English and Hebrew words more accurately in the right visual field, while left-handed Ss recognized English more accurately in the right visual field and Hebrew more accurately in the left visual field.

The finding of a right visual field superiority for Hebrew words is quite damaging to those who hold that only directional scanning effects are responsible for the right visual field superiority found for tachistoscopic recognition tasks. Since Hebrew words are read from right-to-left, a directional scanning hypothesis must

predict a left visual field superiority, which is the opposite of what actually occurred. Indeed, as has previously been noted, the lack of a significant right visual field superiority for Hebrew in two early studies (Mishkin and Forgays, 1952; Orbach, 1952) has been cited by proponents of the directional scanning hypothesis as contradicting any influence of speech-brain asymmetry on visual field asymmetry. However, the differences in asymmetry between English and Hebrew words in Orbach's study does suggest that directional scanning effects were also operative. With the English words, both directional scanning and speech-brain asymmetry effects would favor a right visual field asymmetry resulting in a large right visual field superiority for both right- and left-handers. With the Hebrew words, the speech-brain asymmetry effect would again favor a right visual field superiority; however, directional scanning effects would favor a left visual superiority. Compounding the effects of visual scanning with speech-brain laterality results in a smaller right visual field superiority for right-handers (where speech-brain asymmetry is most consistent) and a slight left visual field superiority for left-handers.

Studies using Simultaneous Visual Field Stimulation

While a consistent right visual field superiority for verbal materials has been demonstrated in the studies using successive tachistoscopic presentation (stimuli presented either to the left or right or a central fixation point), this has not been true with simultaneous tachistoscopic presentation. When stimuli are presented simultaneously to the left and to the right of a central fixation point, a

left visual field superiority has been found for letters (Bryden, 1960; Bryden and Rainey, 1963; Heron, 1957; Kimura, 1959), geometric forms (Bryden, 1960; Bryden and Rainey, 1963; Kimura, 1959), nonsense words (Heron, 1964), and outlines of familiar objects (Bryden and Rainey, 1963). Superior recognition in the right visual field was found for outlines of familiar objects (Wyke and Ettlinger, 1961) and for letters under conditions (Kimura, 1959; Heron, 1957).

The finding of a left visual field superiority under most conditions of simultaneous tachistoscopic stimulation has usually been attributed to a second kind of directional scanning tendency; that is, there is a tendency to scan the left visual field before the right when both fields are stimulated simultaneously. Kimura (1966) has suggested that fundamentally different factors underlie the asymmetry observed with simultaneous as opposed to successive random tachistoscopic stimulation. She hypothesized that under simultaneous visual field stimulation, directional scanning tendencies would predominate (i.e., left visual field superiority). Under successive random tachistoscopic presentation, the type of stimulus material (i.e., verbal versus nonverbal) will determine which visual field shows more accurate recognition.

The Visual and Auditory Procedures as Predictive Instruments

Studies have been reviewed concerning the visual and auditory procedures which seem to correlate with the functional asymmetry of the two hemispheres in man. These studies were reviewed in light of the need for development of correlates of the speech-brain asymmetry in man, which can be applied to normal Ss.

Two questions need to be asked of such techniques if they are to be applied for predictive purposes. First, are they valid measures; that is, do the techniques actually reflect asymmetry in cerebral brain function; and second, are they powerful enough to be useful for predictive purposes.

Both the visual and auditory procedures do seem to validly reflect the underlying asymmetry in speech-brain function. The evidence that these procedures are correlated with cerebral asymmetry is quite similar for the visual and auditory techniques. First, both procedures show a lateralized asymmetry in the direction which would be predicted from the asymmetry of the hemispheres and the neuroanatomical pathways (i.e., right visual field superiority for verbal material; right ear superiority for verbal material). Second, both procedures show a reversal of asymmetry for verbal versus non-verbal material. Third, both procedures show a larger asymmetry for right-handed Ss than for left-handed Ss. In addition, the Dichotic Listening Test has been correlated with the Wada sodium amytal test (Kimura, 1961b).

In terms of predictive validity, however, the two techniques show contrasting strengths. The strength of the Dichotic Listening Test lies in its powerful effect (e.g., 87 per cent of the right-handed Ss showed a right ear superiority for the 6-pair condition) and relative freedom from learned contaminating factors. The Dichotic Listening Test has already been used to relate manual skills to speech dominance (Satz et al., 1967), study development of cortical lateralization in children (Kimura, 1963), study speech-brain relationships

and genetic factors using identical twins (Sata, 1968), and study the role of incomplete cortical lateralization in developmental dyslexia (Sparrow, 1968).

The strength of the visual measures lies in the superior neuroanatomical separation of inputs to the two hemispheres. Stimuli presented to either ear go to both the left and right hemispheres via crossed and uncrossed pathways. The ear asymmetry is thus dependent on the relatively greater efficiency of the crossed auditory fibers. In contrast, in the visual system, stimuli presented to the right visual field are processed directly to the left hemisphere and stimuli presented to the left visual field are transmitted directly to the right hemisphere.

However, the visual field techniques which have been developed thus far have not shown usefulness as predictors of speech laterality. First, the only consistently observed right visual field superiority has been found with successive tachistoscopic presentation. It has not been shown, however, that this is as powerful an effect across Ss as has been observed in audition. Second, the right visual field superiority that is observed with successive tachistoscopic presentation is dependent on both speech-brain asymmetry and directional scanning effects. Thus, it is a contaminated and somewhat unsatisfactory technique to utilize as a measure of cerebral asymmetry.

Development of New Visual Procedures

This paper describes two experiments which attempt to develop a new paradigm for exploring visual field asymmetry through the use

of short term memory procedures. The technique used is somewhat analogous to the Dichotic Listening Test in audition, since sequences of digit pairs are presented to the Ss. In Experiment I the pairs are presented simultaneously to both visual fields. In Experiment II, the pairs are presented simultaneously to the macula and one visual field. It is hypothesized that the use of simultaneous stimuli, within a short term memory paradigm, may provide a more powerful procedure for enhancing visual field differences in recall. In addition, the use of similar experimental techniques in both the visual and auditory modalities enables the investigator to make more effective comparisons of the asymmetries observed in each modality.

The questions to be answered in these experiments are:

1. Are there differences in accuracy of recall for digits between the left and right visual fields when both are stimulated simultaneously within a short term memory paradigm (Experiment I)? A left visual field superiority would be consistent with Kimura's (1966) directional scanning hypothesis, derived from tachistoscopic simultaneous stimulation studies. A right visual field superiority would suggest speech-brain asymmetry effects analogous to those found in audition using simultaneous stimulation in a short term memory paradigm.

2. Is is possible to increase the visual field asymmetry by controlling for order of report (Experiment II)?

METHOD

Equipment

All experiments were performed in a dimly illuminated room, with one light source directly behind the Ss. The Ss. were seated at a table with their heads positioned on a chin and forehead rest which was permanently mounted to the table. Stimuli were presented at about eye level on a rear-view projection screen five feet in front of the S. A Kodak 16mm Analyst projector (Model Number EP-16 AR) with both variable rheostatic and governor-set speed controls was employed. The governor-set speed control was used in all experiments with the film shown at about 24 frames per second. The stimuli appeared white against the darker background of the screen.

Procedure

The stimuli used were single digits (0-9) which were projected at 3° of visual arc from a central fixation point. Each digit subtended approximately 45' of arc in height and 30' in width. At the beginning of each trial, a central fixation point appeared for one second immediately followed by a sequence of digit pairs. No number appeared more than once in any given trial. In both experiments, 30 trials were used, with the last 15 trials identical to the first except for a reversal of the field to which the digits were projected. The exposure time was 174 msec per pair. This rate was chosen on the

basis of preliminary studies which indicated that this rate was of approximately equal difficulty to the standard auditory rate of two pairs per second. An interstimulus interval of 174 msec was employed only in Experiment I. A between-trials interval of ten seconds was used, during which Ss reported the digits recalled. All responses were recorded by E immediately following each trial.

Subjects

All Ss were undergraduates at the University of Florida, Gainesville. The Ss ranged in age from 16 to 30. The Ss were screened for visual acuity using a Snellen Eye Chart, with a required corrected or uncorrected acuity of at least 20/40 for each eye.

Experiment I

This experiment investigates visual field asymmetry and order of report with three pairs of digits in a free recall situation.

Method

Three pairs of digits were presented in 870 msec. In each digit pair, one digit was projected to the left and one digit to the right of a central fixation point, which remained on the screen during all three digit pairs. Subjects viewed three practice and 30 test series of digits, binocularly.

Subjects

Twenty-seven right-handed and fourteen left-handed male and female Ss were tested. These Ss were classified as right- or left-handed on the basis of a ten-item questionnaire.

Instructions

Subjects were instructed to fixate on the central fixation point throughout each trial. They were also reminded to concentrate on the central point several times during the administration of the trials. Subjects were asked to report as many numbers as they could remember in any order they wished. However, Ss were not permitted to combine numbers (e.g., 27 instead of 2, 7).

Results

Table 1 shows the per cent correct recall for each visual field in Experiment 1. The data were analyzed for differences in total recall between fields and for differences in visual field asymmetry between right- and left-handers.[1] No significant differences in mean recall were found between visual fields ($F = 3.60$, $p < .1$) and between left- and right-handers ($F = 3.04$, $p < .1$). However, significantly more Ss had better recall in the left visual field ($Z = 1.65$, $p < .05$). The interaction of visual field by handedness was not significant ($F = .05$, $p < .1$), indicating no significant difference in visual field asymmetry between left- and right-handers.

Table 2 presents the frequency of occurrence of several types of orders of report for Experiment I. Four types of orders of report were analyzed: (1) Visual Field (LLL, RRR or RRR, LLL), (2) Attempted Field, (3) Temporal (LR, LR, LR or RL, RL, RL), and (4) Others. Bryden's (1962) criteria were followed for strategies (1) and (2).

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[1]See Appendix A for full analysis.

TABLE I

PER CENT CORRECT BY VISUAL FIELDS AND HANDEDNESS FOR EXPERIMENT I

Handedness	Field	
	Left	Right
Left	92.9	91.4
Right	88.4	86.4
Total	91.3	89.7

TABLE 2

ORDER OF REPORT FREQUENCIES BY PER CENT IN EXPERIMENT I

Order of Report	I
Temporal (L-R)	70.61
Field (L-R)	2.23
Attempted Field	1.00
Other	26.16

The temporal order of report, as defined by Bryden in audition, did not occur in vision. Table 3 presents the temporal order of report as it occurs in vision and audition. As shown in Table 3, the temporal order in vision is a pure left-right effect. Typically, the temporal order occurred as numbered in Table 3; however, on occasion Se began with the last pair of digits.

Experiment II

This experiment was designed to investigate visual field asymmetry under a fixed order of recall. It was felt that using a fixed order of recall would control for the bias of the left-to-right reading effect. Three-pair digit sequences were presented binocularly.

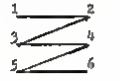
Method

Three pairs of digits were presented in 522 msec. A central fixation point appeared on the screen for one second prior to presentation of each group of digit-pairs. One digit in each pair was then presented at the central point of fixation, the other digit 3° to the left or to the right of fixation. Fifteen trials were run with three digits to the left of fixation and 15 trials with three digits to the right of fixation. Five practice trials preceded each series of 15 trials. One-half of the Ss viewed the 15 right visual field trials first; the second half viewed the 15 left visual field trials first.[2] Thus, a two-by-two Latin Square was generated with

[2]Data on other visual measures administered to Ss are presented in Appendix B.

TABLE 3

TEMPORAL ORDER OF REPORT IN AUDITION AND VISION FOR 3-PAIR CONDITIONS

Audition		Vision	
Left	Right	Left	Right
			

visual fields as one dimension and serial position, the second dimension.

Subjects

Forty-two right-handed males and females.

Instructions

Subjects were asked first to fixate on the central fixation point and then on the three numbers which followed at the point of fixation. Subjects were instructed to report all three digits presented centrally, before recalling any digits presented to the left or right visual field. Subjects were permitted, however, to recall the digits from the center or field groups in any order they wished.

Results

Mean recall and per cent correct for each visual field (delayed half-spans) are presented in Table 4. The data were analyzed for differences in visual field asymmetry and also for practice effects between the first and second set of 15 trials using a Type II analysis of variance. Since a trial was not scored unless the S correctly named all three digits presented centrally, for each S the number of visual field digits recalled was divided by the number of trials scored, to obtain the mean number correctly recalled per trial. Subjects were able to correctly recall the three center digits in 83.77 per cent of the trials. The analysis of variance[3] showed that the right visual field was significantly better in a fixed order of

[3]See Appendix C for full analysis.

TABLE 4

MEAN RECALL AND PER CENT CORRECT BY VISUAL FIELDS

Field	Mean	Per Cent
Left	14.6	32.4
Right	17.9	39.8

recall ($F = 28.3$, $p < .001$). There was also a significant position effect, with the last 15 trials recalled more accurately than the first 15 trials ($F = 23.17$, $p < .001$). A significant interaction occurred between visual field and position ($F = 10.15$, $p < .005$), which was due to a greater position effect when the left visual field trials followed the right visual field trials. Further analysis of data indicated that the right visual field superiority was due primarily to serial position effects (i.e., better right visual field recall on the first and second digits of each trial). Table 5 presents the mean recall for each visual field by serial position.

TABLE 5

MEAN RECALL BY SERIAL POSITION AND VISUAL FIELDS

Field	Serial Position			Total
	First	Second	Third	
Left	2.1	3.4	9.1	14.6
Right	3.4	4.7	9.3	17.9

DISCUSSION

These experiments demonstrated that the visual field asymmetry varied as a function of free versus fixed order of report. Experiment 1 (free order of report) found that more Ss displayed superior recall for digits presented to the left visual field. Recent studies at this University (Hines, et al., 1967; Shell, 1968) have replicated this finding using a four-pair condition. These results are presented in Table 6. Inspection of this table shows that recall was superior for digits presented to the left visual field under both monocular and binocular viewing conditions. The left field superiority, under free recall conditions, was apparently due to the effects of directional scanning and order of report. When digits were presented in simultaneous pairs to each visual field, the digit to the left of fixation was generally reported first. In Experiment I, Ss reported the digits left-to-right (temporal order) on 60.6 per cent of the trials. This order-effect seems to be a direct reflection of the left-to-right reading habit. Thus the results of Experiment I are consistent with the data from simultaneous tachistoscopic experiments (Kimura, 1966).

Experiment II was designed to minimize directional scanning, while controlling for order of report. Subjects under this condition showed superior recall for digits presented to the right visual field. This reversal in visual field asymmetry was striking; roughly 80 per cent of the Ss showed a higher corrected mean recall in the right visual field. This reversal in visual field asymmetry, when

TABLE 6

PER CENT CORRECT BY VISUAL FIELDS AND EYES UNDER MONOCULAR AND BINOCULAR CONDITIONS*

Condition	Eye	Field	
		Left	Right
Monocular	Left	63.5	59.0
	Right	66.2	59.3
Total		64.5	59.2
Binocular		65.9	63.2

*From Hines, et al., 1969.

directional scanning effects were controlled, lends strong support for the effect of speech-brain asymmetry factors.

An alternate explanation, which has traditionally been invoked to explain right visual field superiority in tachistoscopic studies, is Heron's (1957) directional scanning hypothesis. However, this does not seem adequate to explain the data from Experiment II. Briefly, Heron suggested that it is more difficult to recall the digits in the left visual field because it requires a right-to-left eye movement to the beginning of the stimulus and an additional left-to-right movement to "read" the stimulus. However, the task of first recalling the three center digits in 522 msec was difficult enough (83.7 per cent correct) to require the Ss attention and to insure that they continued to fixate at the center point. Thus, it is doubtful if any eye movements occurred at all. In addition, since only one visual field digit was on the screen at any given time, it is likely that no additional eye movement would be necessary for the left visual field.

The changes in visual field asymmetry related to serial position also contraindicated directional scanning effects. If directional scanning effects of any kind (eye movements, attentional, etc.) were involved then the right visual field superiority would be due to differences in recognition difficulty; that is, it would be easier or more natural to "see" the digits in the right visual field. If this were correct, however, then the visual field asymmetry should be relatively constant across digit pairs, since it would be essentially unrelated to the short term memory aspect of the task.

In contrast to this, the data suggest that the visual field asymmetry was directly related to the short term memory aspect of the task and varied systematically, according to serial position (see Table 6). The Ss showed equal recall for the stimuli in each visual field on the last (third) digit presented; however, they recalled 1.4 times as many digits in the right visual field on the second digit presented and 1.6 times as many digits in the right visual field on the first digit presented.

The pattern of serial order differences in visual field asymmetry seems to be most consistent with predictions made from the more direct access between the right visual field and the language processing centers of the left hemisphere. Differences in ear asymmetry with Dichotic Listening have also been related to serial order effects (Barts, 1967).

The investigation of visual field asymmetry under instructed conditions (Experiment II) also proved a paradigm in which Broadbent's (1954) auditory model of short term memory could be extended to vision and correlated with the underlying neuroanatomical pathways. Thus, those digit half-spans which the Ss in Experiment II were instructed to report first refers to Broadbent's p-system. The fact that these half-spans were presented at the macula indicates that the information was transmitted via both crossed and uncrossed pathways to both cerebral hemispheres. Conversely, those half-spans which the Ss were instructed to report second refers to Broadbent's short term storage or s-system. The fact that these half-spans were presented only to

the left or to the right visual field indicates that the information which was delayed, was transmitted via crossed and uncrossed pathways to the hemisphere contralateral to the field of stimulation. This paradigm thus provides an opportunity to explore parameters of short term memory (s-system) transmitted either directly (i.e., left hemisphere) or indirectly (i.e., right hemisphere) to the language processing centers of the brain. In contrast to the auditory model, the visual paradigm would seem to offer a more suitable framework for testing deductions from Broadbent's theory and relating these findings to neurological and functional differences in the brain.

The analysis of orders of report in the present study showed that, under free recall, Ss adopted grouping strategies that differ from those reported in audition (Bryden, 1962). The visual analogue for the ear-order report in audition corresponds to the grouping by visual field in the present study (LLL, RRR or RRR, LLL). In Experiment I (3-pair trial), Ss grouped the digits by visual field in only 2.3 per cent of the trials. The corresponding frequency in audition (ear-order) is 77 per cent for the three pairs of digits. The most frequent grouping strategy in Experiment I was the temporal (L-R) order of report which occurred on 70.6 per cent of the trials and on only 8.8 per cent of the trials in audition (Bryden, 1962). Thus, an inverse relationship seems to exist between orders of report in audition and vision.

By contrast, the percentage of overall recall in Experiment I corresponded closely to those percentages reported in audition.

Bryden (1963) and Sats, et al. (1965) reported an accuracy ranging from 91 - 95 per cent for 3-pair trials. The corresponding percentage in Experiment I was 90.5 per cent.

Implications for Future Research

The results of Experiment II suggest that it may be possible to produce a consistent right visual field asymmetry across Ss, using a short term memory paradigm. This finding needs to be replicated and extended.

1. In Experiment II a significant practice effect occurred which complicated the assignment of Ss into a left or right field dominant group. Use of a repeated abba design might control more effectively for practice effects.

2. The differences in asymmetry across serial positions suggest that the right visual superiority might be increased by increasing the number of pairs presented. This would be consistent with results from the auditory studies (Sats, 1967).

3. If the visual field asymmetry is due to the speech-brain asymmetry and the more direct connections between the right visual field and the left hemisphere, other inferences are then possible.

a. The asymmetry should be larger for right-handed Ss.

b. The asymmetry should reverse for recognition of non-verbal stimuli.

c. The results of the visual field test should correlate with the results of the Dichotic Listening Test.

If these predictions are confirmed, then the evidence that the visual field asymmetry is related to speech-brain asymmetry would be quite convincing. Also a positive correlation between the visual field test and Dichotic Listening Test would provide important construct validity for these techniques. The techniques could then be applied with assurance to the problems of assessing the development, behavioral correlates and genetic correlates of speech-brain laterality in normal Ss.

SUMMARY

Visual field differences were investigated in two experiments which employed simultaneous methods of stimulation in a recall or short term memory task. Experiment I presented simultaneous digit sequences (3 pairs) to each visual field, under free order of recall. Subjects recalled more digits from the left visual field under these binocular viewing conditions. The left visual field superiority was postulated to be a function of directional scanning effects similar to those occurring under conditions of simultaneous tachistoscopic presentation. Experiment II presented three pairs of digits, with one digit in each pair at the point of fixation and the other three in either the left or right visual field. Subjects were instructed to report the digits at fixation before recalling those presented to the visual field. This modification resulted in superior recall for these delayed half-spans presented to the right visual field. It was shown that the more direct connections between the right visual field and the speech centers of the left hemisphere were probably responsible for this striking and consistent right visual field superiority.

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APPENDICES

APPENDIX A

ANALYSIS OF VARIANCE FOR EXPERIMENT I

Source	Ss	df	MS	F
Between Ss	4791.39	46		
Hands	346.88	1	346.88	3.04
Error (b)	4444.5	39	113.96	
Within Ss	475.00	46		
Fields	41.02	1	41.02	3.60
Fields x Hands	.554	1	.554	.04
Error (w)	443.42	38	11.41	

APPENDIX B

VISUAL MEASURES ADMINISTERED IN EXPERIMENT II

Subjects in Experiment II were administered tests for sighting and reading "dominance." Reading dominance was measured on the Keystone Ophthalmic Telebinocular at a distance equivalent to 158.5 inches. The reading material consisted of two short paragraphs, one of which was presented to the left eye and the other of which was presented simultaneously to the right eye. The two paragraphs were identical except for sight words, and were presented to identical retinal areas of each eye. Subjects were not told the purpose of the test, but were told that they would be presented with a paragraph which they were to read aloud.

The sighting test consisted of having Ss sight a light bulb about 50 feet away through a small hole in a piece of paper.

Subjects were then broken into left or right "dominant" groups on the basis of their performance on the reading, sighting, and visual field test scores. Neither the sighting or reading dominance was significantly related to the results of the visual field test (Sighting dominance: $\chi^2 = 3.18$; Reading dominance $\chi^2 = 4.19$) but they were significantly related to each other ($\chi^2 = 11.14$).

APPENDIX C

ANALYSIS OF VARIANCE FOR EXPERIMENT I

Source	Ss	df	MS	F
Between Ss	9.815	41		
Fields x Position	1.995	1	1.99	10.178*
Error (b)				
Within Ss	3.209	42		
Fields	.992	1	.992	28.34**
Position	.811	1	.811	23.17**
Error (w)	1.406	40	.035	

*$p < .05$.

**$p < .001$.

BIOGRAPHICAL SKETCH

David Arnold Hiess was born December 10, 1941, in Philadelphia, Pennsylvania. He graduated in June, 1959, from Collingdale High School in Collingdale, Pennsylvania. He studied psychology at Rollins College in Winter Park, Florida, obtaining a Bachelor of Arts degree in June, 1963. In September, 1963, he enrolled in the Graduate School of the University of Florida, where he received a Master of Arts degree in December, 1964. He is not married.

This dissertation was prepared under the direction of the chairman of the candidate's supervisory committee and has been approved by all members of that committee. It was submitted to the Dean of the College of Arts and Science and to the Graduate Council, and was approved as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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